Flight Tests

Atlantic Aero A-36

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The Bonanza is one of the most heavily modified aircraft in the general aviation fleet. In terms of design age it is also one of the oldest – starting out with a first flight in 1945 with a 165 horsepower engine at a maximum gross take-off weight of 2550 pounds with a top speed at sea level of 184 mph.

Today, this basic aircraft has been modified and updated into a 300 horsepower turbocharged speedster that flies in the flight levels at maximum speeds up to 245 mph and has a maximum gross take-off weight of 3850 pounds. Hence, when I learned that a company had 'stuffed' a 310 horsepower normally aspirated engine into an A-36 and modified the cowling it was a case of *deja vu*. However, my curiosity, which has gotten me into heaps of trouble and cost gobs of money and time over the years, was aroused. So, with more than my usual healthy dose of skepticism and the phone number in hand I called John Ackerman, the VP of Sales/Technical Services, at Atlantic Aero in Greensboro, NC. John was understandably enthusiastic about the aircraft. However, when he readily agreed to my suggestion that I fly down to Greensboro and do formal level flight performance and rate-of-climb flight tests on the aircraft, I was intriqued enough to set a date. The weather, the aircraft schedule and our two personal schedules resulted in several months delay in actually getting to Greensboro to perform the flight tests.

The modifications

When intially approaching the modified aircraft (see Figure 1), a 1977 A-36 (N44927), the impression is that not much has been done to it. Upon closer inspection it is obvious that the three-bladed propeller is made by Hartzell and has swept tips (green arrow 1 in Figure 2). The propeller also appears to be a bit bigger in diameter. In fact, it is an 82 inch diameter Super Scimitar propeller (F80-68). Next, the nose

Figure 1. Initial impressions.

bowl appears to be split into upper and lower halves (black arrow in Figure 2). Furthermore, it is obvious that the nose bowl intakes have been modified (red arrow in Figure 2). Specifically, the upper engine cooling air intakes are no longer completely open from right to left, *and* the engine manifold intake below the landing light has disappeared (blue arrow in Figure 2). The excellent fit and finish of the nose bowl leads to the realization that it is constructed of carbon fiber (see Figure 3). Lifting the engine compartment door immediately confirms that it, too, is constructed of carbon fiber. The new split-nose bowl and engine compartment doors weigh a bit less than the original metal parts.

One look in the engine compartment (see Figure 4) says that this is *not* the normal IO-550-B that is original equipment on the A-36. In fact, it is a 310 BHP (+5% -0%) 2000 hour TBO IO-550-R fitted with balanced flow fuel injectors. Immediately apparent is that a tuned intake manifold has been moved to the top of the engine. That also explains why there is no filtered engine intake in the nose bowl below the landing light. The filtered engine intake is now inside the engine compartment, located behind the left intake duct just in front of the green hose in Figure 4 (see the

Figure 2. Propeller and nose bowl.

Figure 3. Carbon fiber upper nose bowl. (Courtesy of Atlantic Aero.

white arrow). The net result is that the area of the nose bowl and engine air intakes has been reduced to less than 1/3 that of the original metal nose bowl. A tuned stainless steel multiple slip joint exhaust system has also been fitted to the aircraft.

With the reduction in intake area, there might be some concern about inadequate or uneven engine cooling, as is typical of the original cowl intake design. However, during the flight tests, cylinder head temperatures were well below 300° F in both level flight and climb. Furthermore, the cylinder head temperatures were consistent from cylinder to cylinder, as displayed on a JPI graphic engine monitor, as were the exhaust gas temperatures.

The flight tests

The flight tests were conducted on 3 December 2003 in the vicinity of Greensboro, NC. Takeoff weight was 3166 ± 5 lbs, including full fuel, nine quarts of oil, pilot and flight test engineer and miscellanous equipment. During the flight, while data was being taken, the weight decreased from 3099 lbs to 3051 lbs as fuel was consumed. The tests were conducted at a pressure altitude of 6000 feet for a range of manifold pressures from 20 to 23.5 in Hg, varied in one inch increments until full throttle at 23.5 in Hg was reached. Manifold pressure was determined using the aircraft manifold pressure gauge. Propeller RPM ranged from approximately 2000 to 2400 RPM

Figure 4. Engine compartment. (Courtesy of Atlantic Aero.)

in approximately 100 RPM increments as measured with a stroboscopic PropTach. These manifold pressure and propeller combinations resulted in horsepower available powers from 129 to 219 BHP, as determined using the Continental IO-550-N power curves corrected for temperature. The outside air temperature decreased from 31° F to 29° F during the tests. The engine was consistently leaned to 100° F rich of peak EGT using the JPI graphic engine monitor. A total of five data points on the front side of the power-required curve were obtained.

True airspeed was determined using GPS and the horseshoe heading technique. The horseshoe heading technique uses the GPS ground speed observed in steady level flight during three legs, each at a 90° heading from the previous leg, to eliminate the effect of wind and obtain the true airspeed (TAS).[†] An S-TEC 65 autopilot in heading mode with altitude hold engaged was used to minimize both heading and altitude excursions. On each leg, both the aircraft indicated airspeed (IAS) and GPS ground speed were allowed to stabilize prior to data acquisition. As a crosscheck, a second GPS ground speed was taken approximately 30 seconds after the first.

The horseshoe heading technique yields simple equations, which can easily be coded into a spreadsheet, for the true airspeed, wind speed and wind direction. Here, we are only interested in TAS (V_T) given by

$$V_T = \frac{1}{2}\sqrt{P \pm \sqrt{P^2 - 2(2Q^2 - 2RQ + R^2)}} \tag{1}$$

where $P = V_1^2 + V_3^2$, $Q = V_2^2 - V_3^2$ and $R = V_1^2 - V_3^2$ and again V_1, V_2 and V_3 are the GPS ground speeds on the three legs.

Unfortunately, after the level flight performance tests, the weather deteriorated enough that only a single rate of climb test was conducted. The results for the rate of climb test run are not reported here.

The results

Flight test results are shown in Figure 5. The solid diamond symbols show the uncorrected flight test data. The black line through the diamond symbols is a parabolic curve fit to the uncorrected flight test data. The open triangular symbols show the flight test data corrected for temperature effects and referred to a standard aircraft weight of 3400 lbs. The dashed line is a parabolic curve fit to the corrected flight test data. The chain-dash line represents performance data for an aircraft reference weight of 3400 lbs on a standard day taken from the Beech A-36 pilot operating handbook (POH revised 9/1996) for an aircraft equipped with an IO-550-B 300 horsepower engine and a McCauley 80 inch diameter three-blade propeller fitted with the 82NDB-2 blades.[††] The parabolic equations for the curve fits are shown on the figure. The R^2 value indicates the 'goodness' of the fit. The closer the R^2 value is to 1.0, the better the fit with 1.0 being a perfect fit.

In order to compare the results for different engines, the values for brake horsepower shown on the ordinate (vertical axis) are actual brake horsepower and *not* percent horsepower. Correcting the flight test results for a reference weight of 3400 lbs and reference standard day temperature effects was accomplished using standard

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[†] See www.nar-associates.com/technical-flying/horseshoe_heading/horseshoehead.pdf for details of the horseshoe heading technique.

[††] The specifications call for a minimum propeller diameter of 78.5 inches and a maximum diameter of 80 inches.

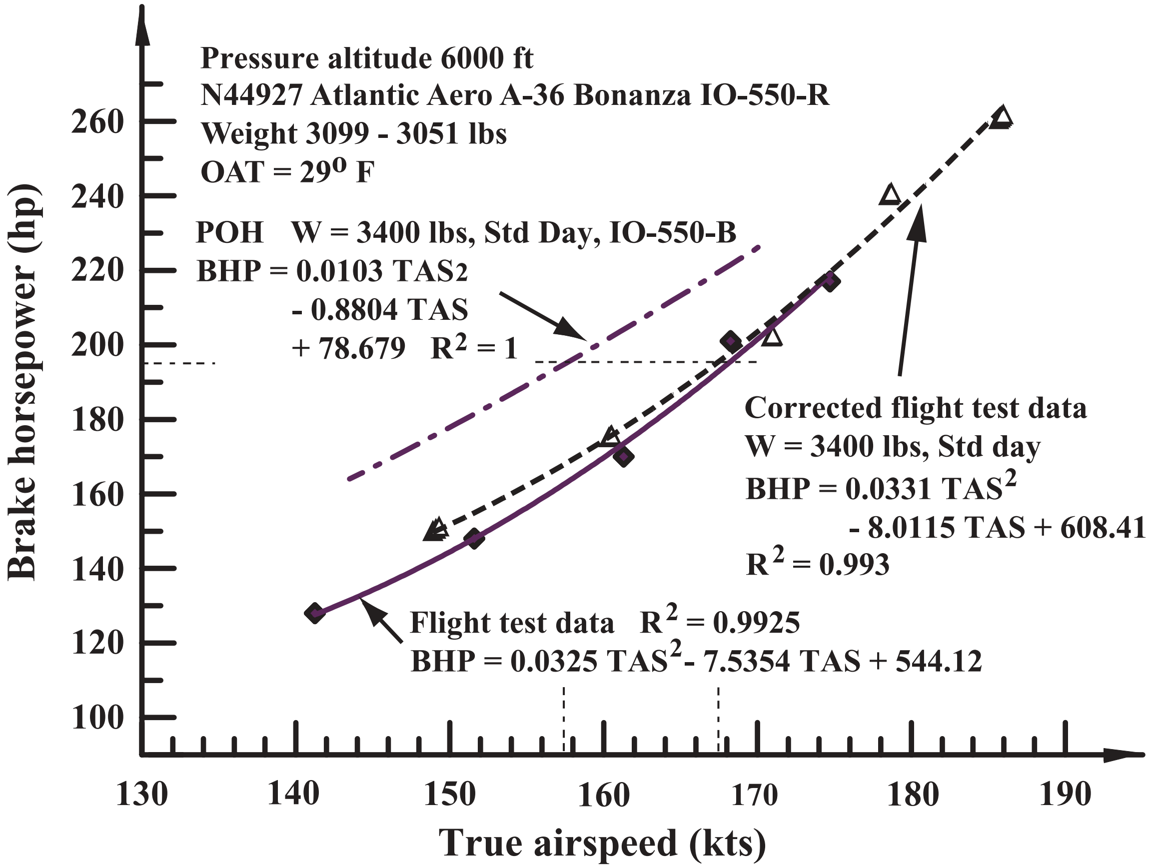

Figure 5. Level flight performance flight test results.

techniques. Specifically, the true airspeed obtained during the flight tests was corrected to that for a standard weight of 3400 lbs using

$$V_{\texttt{std}} = V_{\texttt{test}}\sqrt{\frac{W_{\texttt{std}}}{W_{\texttt{test}}}\frac{T_{\texttt{std}}}{T_{\texttt{test}}}}$$

where V is the true airspeed, W is the weight and T is the temperature. The subscripts `std` and `test` indicate standard and test conditions, respectively. The power required to attain the standard true airspeed at the standard conditions is given by

$$P_{\mathrm{R}_{\texttt{std}}} = P_{\mathrm{R}_{\texttt{test}}}\sqrt{\left(\frac{W_{\texttt{std}}}{W_{\texttt{test}}}\right)^3\left(\frac{T_{\texttt{std}}}{T_{\texttt{test}}}\right)^3}$$

where P_{R} represents the power required.

In Figure 5, the light horizontal dashed line corresponding to 195 brake horsepower intersects the POH curve for the standard IO-550-B powered A-36 and the corrected flight test curve for the Atlantic Aero IO-550-R powered modified A-36 at true airspeeds of approximately 157 and 167 kts, respectively, as indicated by the light vertical dashed lines on the TAS axis. An increase in TAS of 10 kts for the same available power is significant. Figure 6 shows the increase in TAS for other available

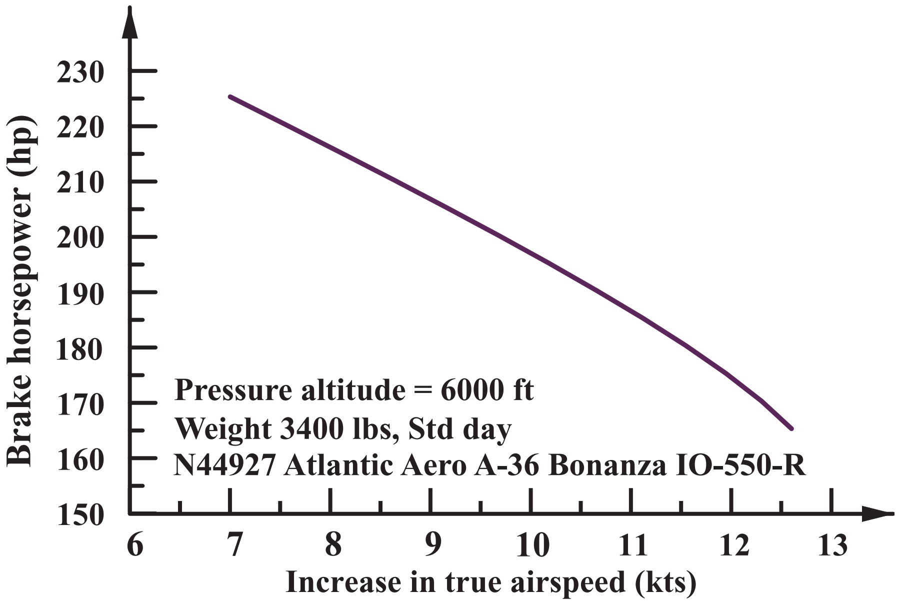

Figure 6. Increase in true airspeed.

powers. Figure 6 also shows that the increase in TAS for a given available power decreases with increasing available power.

Explanation of the TAS increase

In steady level flight, thrust available equals thrust required equals drag, hence the increase in TAS can only come from either increased thrust available or decreased drag. Increased thrust available results from either increased power available to the propeller or from propeller characteristics.

Propeller effects

The 82 inch diameter Hartzell Super Scimitar three blade propeller is 2 inches larger in diameter and 255 square inches (1.77 sq. ft) larger in area than the standard 80 inch McCauley three blade propeller. Furthermore, the increased propeller disk area is at the tip where it is most effective in producing thrust. Simple momentum (actuator disk) propeller theory shows that propeller thrust is directly proportional to the propeller disk area and the air density. Hence, everything else being equal, the increase in thrust is

$$\frac{Thrust_{82}}{Thrust_{80}} = \frac{Area_{82}}{Area_{80}} = \left(\frac{d_{82}}{d_{80}}\right)^2 = \left(\frac{82}{80}\right)^2 = 1.0506$$

where d is the diamenter of the propeller. The velocity increase is proportional to the square root of the thrust, i.e., proportional to the change in propeller diameter. Hence,

$$V_{82} = V_{80}\frac{82}{80} = 1.025$$

or about 2.5%. At 65% BHP (195 BHP) for an IO-550-B this represents an increase of about 4 kts (3.93 kts) true airspeed.

Unaccounted-for power available effects

The more even air distribution to the cylinders provided by the tuned induction system along with the more even fuel distribution provided by the balanced flow fuel injectors can result in more and more even power at the cylinders. Reducing exhaust system back pressure with a tuned exhaust system can also result in additional available brake horsepower. However, at cruise velocities modest increases in available brake horsepower have minor effects on true airspeed. For example, an unaccounted-for additional increase of five brake horsepower from 195 to 200 BHP theoretically results in a change in TAS of less that 1.5 kts, because the true airspeed varies as the cube root of the power available.[†]

Reduction in parasite drag effects

Engine cooling drag results in an increase in the aircraft parasite drag. Engine cooling drag is known to be proportional to the cross-sectional area of a nacelle/fuselage and the cowl inlet area as well as the shape of the inlet and surrounding airframe. Estimation of engine cooling drag is difficult at best. Extracting individual performance increments from flight test data when multiple modifications of the aircraft have occurred is even more difficut. However, some back of the envelope estimates show whether the flight test results given above are reasonable. (You can skip the next couple of paragraphs if you are not interested in the details!)

Details Drag associated with engine cooling is known to contribute as much as 25% of the aircraft parasite drag in the clean configuration. Considering that the parasite drag area, f, of an A-36 Bonanza is approximately 3.5 ft^2. The parasite drag coefficient of the A-36 based on a wing area of 181 ft^2 is thus approximately $C_{D_0} = 0.0193$ ($C_{D_0} = f/S_{\text{wing}} = 3.5/181 = 0.0193$). Twenty-five percent of C_{D_0} is 0.0483! The Bonanza is not quite that bad. From World War II reports, K. D. Wood [††] conservatively estimates that the cooling 'proper' drag coefficient based on cross-sectional area of the body is 0.1. Just behind the nose bowl, the A-36 fuselage cross-sectional area is approximately 5.56 ft^2. Hence, the contribution of cooling drag to the total parasite drag of the A-36, based on wing area, is estimated as 0.00307 ($(0.1)(5.56)/181 = 0.00307$) or about 16% of the total parasite drag. The cooling drag is also known to be proportional to the cooling inlet area. Recall that the inlet area for the new nose bowl is approximately 1/3 that of the original nose bowl, it is reasonable to estimate that the cooling drag contribution to the total parasite drag is reduced by two thirds to 0.00102, i.e., by about 11% of the total parasite drag. This corresponds to a reduction in parasite drag area, f, of 0.37 ft^2. Doesn't sound like much does it? However, it is quite significant. Let's see what the effect is on the true airspeed.

Again, the velocity increment for changes in parasite drag is proportional to the cube root of the change in parasite drag. Thus, the 11% reduction in aircraft equivalent parasite drag area results in a 3.5% estimated increase in TAS ($\sqrt[3]{f_{\text{old}}/f_{\text{new}}} = \sqrt[3]{1.11} = 1.035$). At 195 BHP, which corresponds to 65% power for the IO-520-B engine and a TAS of 157 kts, the estimated increase in TAS is 5.5 kts to 162.5 kts

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[†] See WBS Jan/Feb 1998 pp. 15-17 or www.nar-associates.com/technical-flying/engine_upgrade/io550.pdf for the details.

[††] See K. D. Wood, *Aerospace Vehicle Design*, Vol. 1, *Aircraft Design*, Johnson Publishing Co. Boulder, CO, 1963.

($157 + 0.035 \times 157 = 162.5$ kts). Hence, the increase in TAS due to a reduction in cooling parasite drag along with the increase due to the larger propeller diameter and the unaccounted-for increase in brake horsepower resulting from tuning of the intake and exhaust manifolds mentioned above, suggests that the increase in TAS for the Atlantic Aero modifications is reasonable. Specifically, an estimated 4 kt increase from the larger propeller and an estimated 5.5 kt increase from the parasite drag reduction plus a little bit from the power increase is a 9.5+ kt increase which is close enough to the observed 10 knot increase.

Conclusions

A level flight performance flight test was performed on an Atlantic Aero A-36 equipped with a 310 BHP IO-550-R engine with tuned intake and exhaust manifolds, a new nose bowl and an 82 inch three bladed Hartzell Super Scimitar propeller. The flight test showed a substantial increase in true air speed compared to values taken from the pilot operating handbook for a standard 300 BHP IO-550-B equipped with an 80 inch McCauley three bladed propeller at the same available brake horsepower. The true airspeed increase is attributed to increased thrust from the larger diameter propeller, increased unaccounted-for horsepower from the tuned intake and exhaust manifolds and reduction in parasite drag from engine cooling. Cylinder head temperatures, as well as exhaust gas temperatures, were consistent from cylinder to cylinder, indicating more even engine cooling and combustion.

If you have an engine replacement in your near future (or just want to go faster), these modifications appear to provide a real true airspeed increase and to address the problem of uneven cylinder cooling typical of the standard installation. However, be aware that the results reported here are for a single limited flight test for a specific aircraft. Your results may vary. I would sure like to be able to do careful before and after flight tests for each of the individual modifications in order to be able to accurately identify the increase/decrease in true air speed for each modification. An STC covering the E33A, E33C, F33A, F33C (utility category), 35-C33A, S35, V35, V35A, V35B, 36, and the A36 is available from Atlantic Aero.[†]

[†] See http://www.atlantic-aero.com for the details.